Microbiological contaminants in food processing environments

Sanitation and Environmental Monitoring Workshop 2018

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Learning objectives

- Learn about microbiological contaminants in food processing environments.
- Review sources of contamination.
- Gain understanding of factors influencing microbial growth and survival.
- Introduce ways to control microbial hazards.

South Africa listeriosis outbreak

"As of 02 March 2018, a total of laboratory-confirmed cases have risen to 948, still counting from January 2017. Of these 948, a total 659 patients have been traced and 180 of them have unfortunately died. This constitutes 27% case fatality rate."

Minister of Health Dr. Aaron Motsoaledi

How does it get contaminated?

Food processing environment

What are the microbial hazards?

Why and how do they survive?

Where do they come from?

How do we prevent or control them?

Definitions

- Hazard
  - Any biological, chemical (including radiological), or physical agent that has the potential to cause illness or injury.
    - 21 CFR 117.3
- Known or reasonably foreseeable hazard
  - A biological, chemical (including radiological), or physical hazard that is known to be, or has the potential to be, associated with the facility or the food.

Biological Agents Cause More Outbreaks

Reported Foodborne Illness Outbreaks 2009–2013

Hazard Type	Outbreaks	Illnesses	Hospitalizations	Deaths
Biological	2,545	52,750	3,552	99
Chemical	163	663	67	5
Physical	Not collected			
Unknown	1,204	13,770	286	3

Adapted from: CDC Surveillance for Foodborne Disease Outbreaks, United States Annual Reports, 2009-10, 2011, 2012, 2013

FSPCA
FOOD SAFETY PREVENTIVE CONTROLS ALLIANCE

Food processing environment

What are the microbial hazards?

Why and how do they survive?

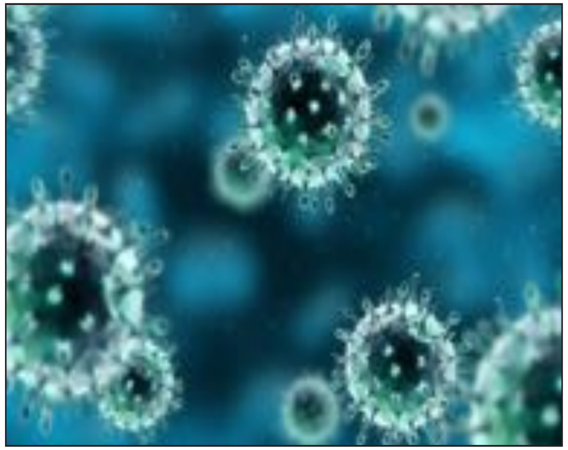
Where do they come from?

How do we prevent or control them?

Biological or microbial hazards

- Pathogens
  - Organisms of concern because they can make people ill
  - Any agent that causes disease in humans, animals or plants
    - Bacteria, viruses, protozoans

Listeria monocytogenes
(Photo source: CDC, Jennifer Oosthuizen)



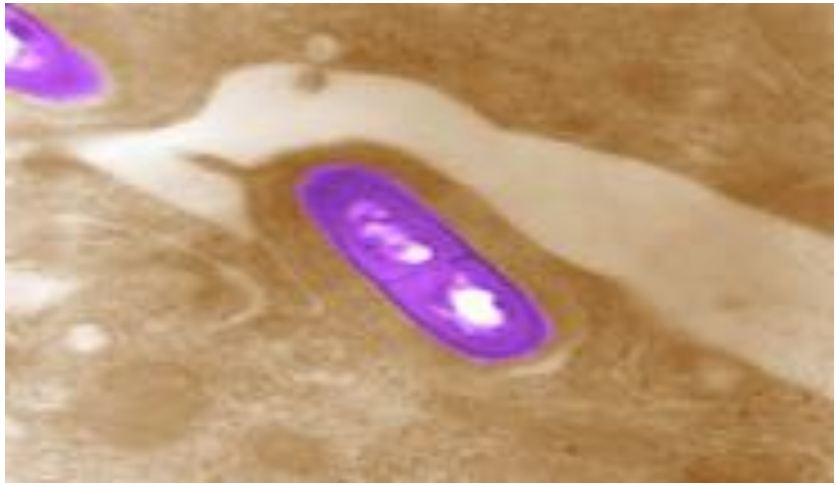
Enterovirus

Giardia

Meals et al., 2013.
TechNotes 9 - National Nonpoint Source Monitoring Program.

Environmental pathogens of concern in food processing environments

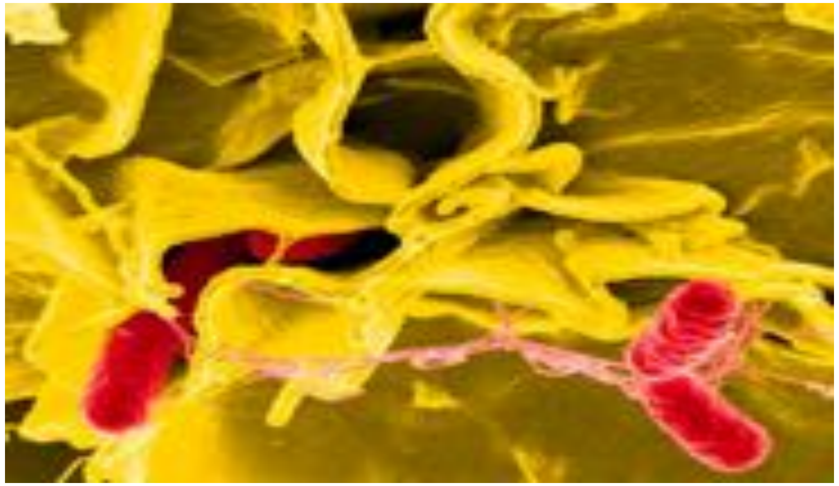
Contaminant of concern in wet RTE environments



Listeria monocytogenes

Photo source: CDC, Dr. Balasubr Swaminathan; Peggy Hayes

Contaminant of concern in dry RTE environments



Salmonella sp.

Photo source: CDC, National Institute of Allergy and Infectious Diseases (NIAID)

Food processing environment

What are the microbial hazards?

Why and how do they survive?

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How do we prevent or control them?

Factors affecting microbial growth

- Microorganisms grow or multiply in numbers when exposed to a favorable environment
- Growth can be associated with:
    - Food spoilage
    - Foodborne diseases
    - Food bioprocessing
- Growth affected by:
    - Food properties/ environment → intrinsic factors
    - Environment in which food is stored → extrinsic factors
    - Microorganism properties → implicit factors

Intrinsic factors

Properties of a food product

- pH
- Water activity (a_w)
- Redox potential (Eh)
- Nutrient content
- Antimicrobial constituents
- Biological composition/ structures

Extrinsic factors

Properties of storage environment that affect microbial survival/growth, external to the food

- Temperature
- Relative humidity
- Gases
- Microbiota competition

Implicit factors

Properties of microorganisms themselves

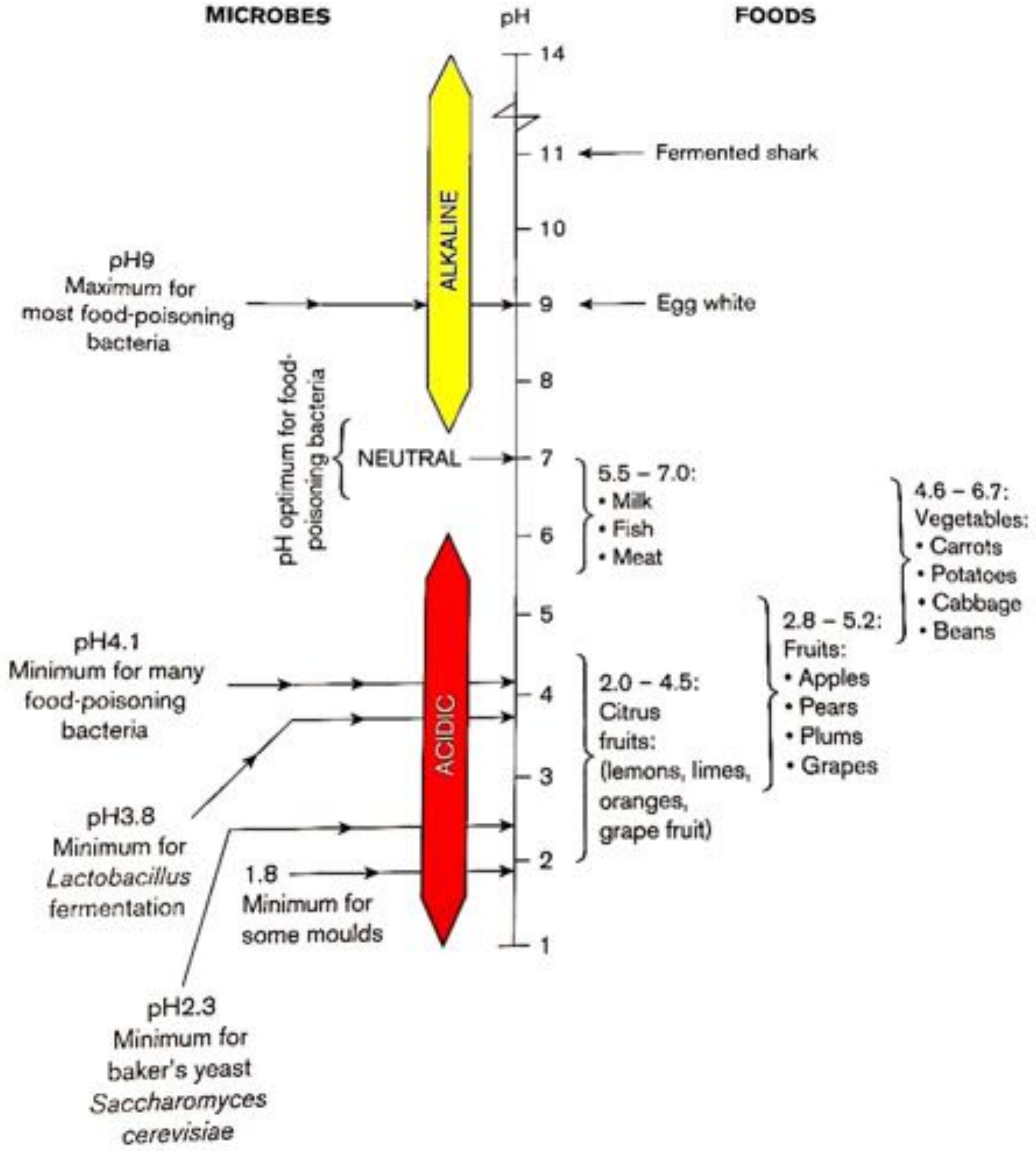
- Exponential phase cells killed more easily by heat, low pH and antimicrobials
- Preadaptation to stress
- Stress response mechanisms

pH

A measure of food's acidity or alkalinity.

Foods with a pH less than 7.0 are acidic.

While a low pH may prevent bacterial growth, some pathogens can survive!

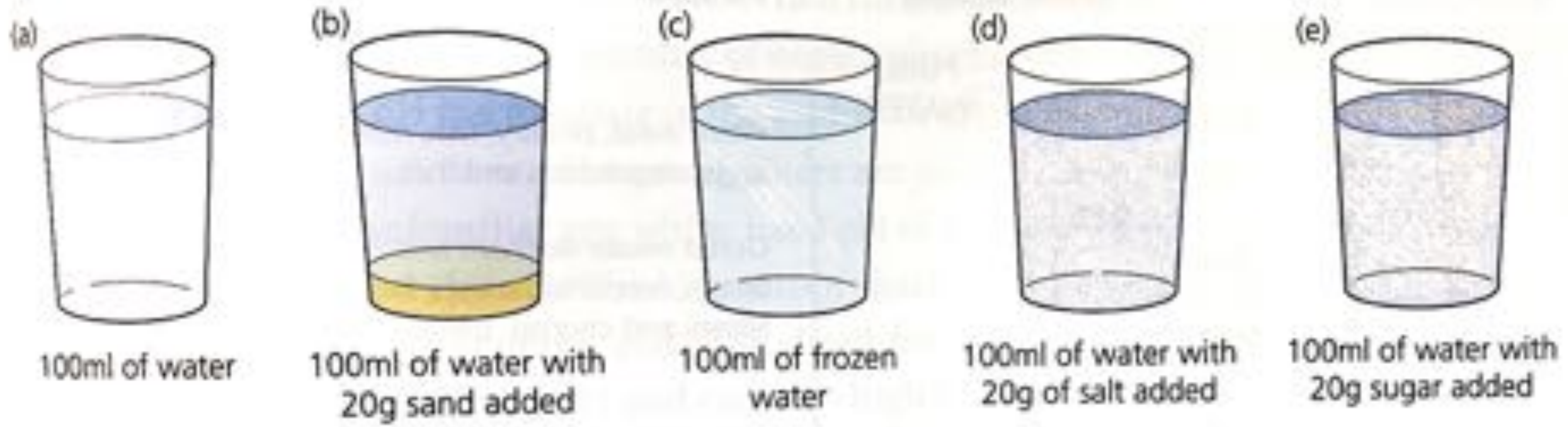


Roller, 2012. Essential Microbiology and Hygiene for Food Professionals. Pg. 131

a_w

"A measure of the free moisture in a food and is the quotient of the water vapor pressure of the substance divided by the vapor pressure of pure water at the same temperature."

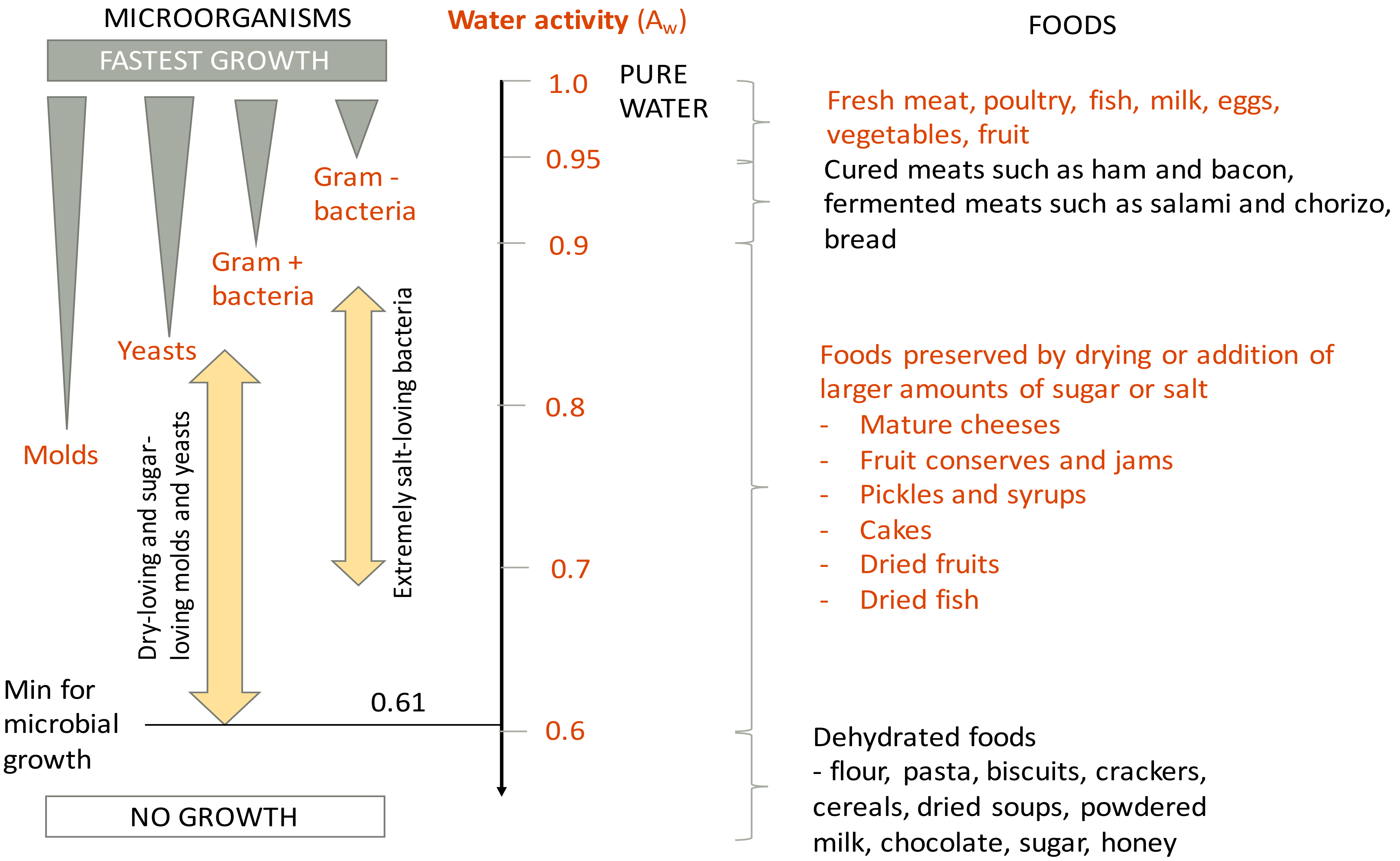
21 CFR 117.3



The availability of water for microbial growth.

Roller, 2012. Essential Microbiology and Hygiene for Food Professionals. Pg. 129

a_w



Roller, 2012. Essential Microbiology and Hygiene for Food Professionals. Pg. 130. Graphic adapted by J. Kovacevic.

Redox potential (Eh)

- Ease with which an element or compound loses/gains electrons
- Unit is mV
  - Aerobes, +mV (oxidative)… O_2
  - Anaerobes, -mV (reductive)… NO_3, SO_4, hydrogen, lactate
- Microbes have different Eh niches

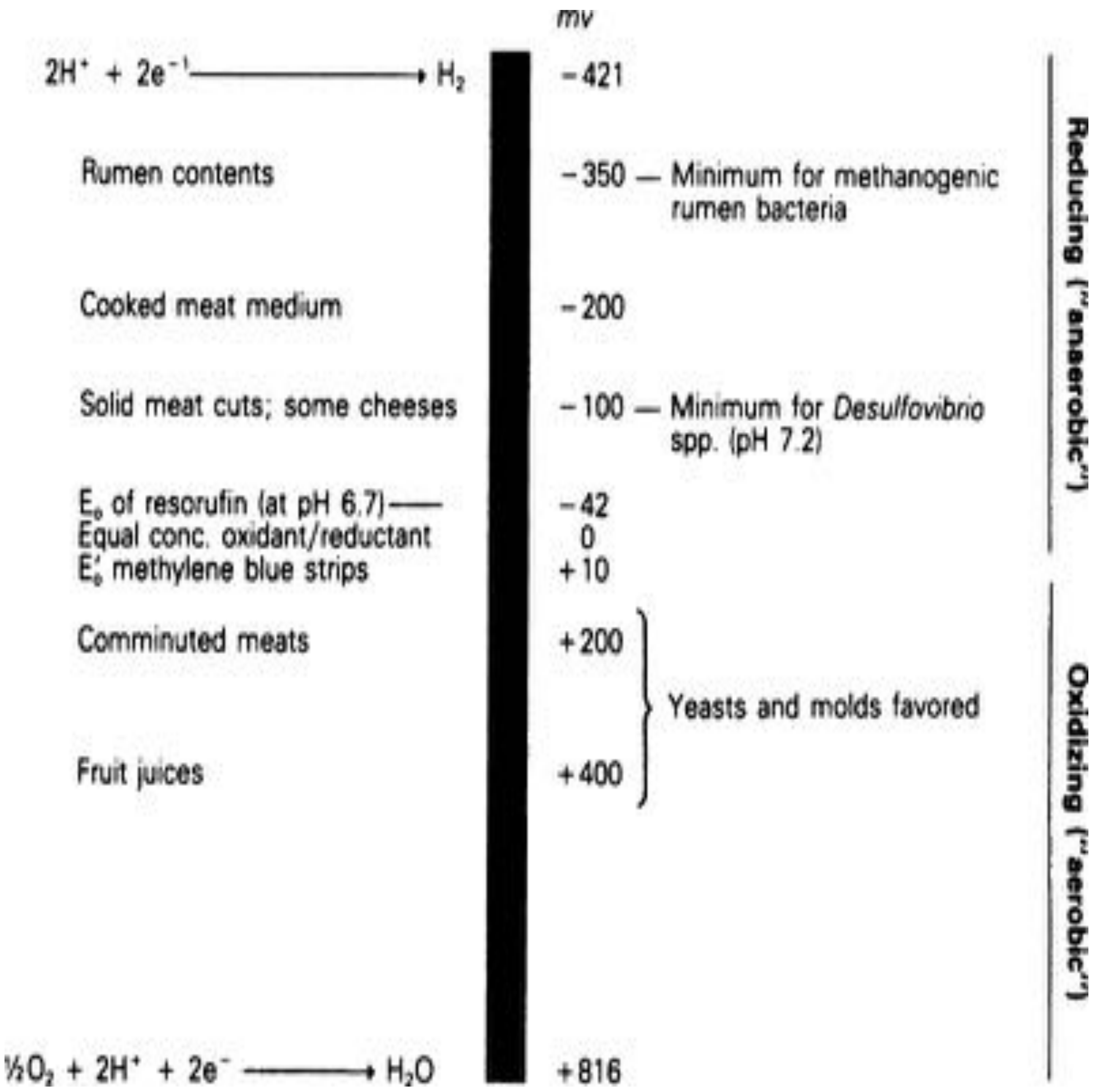
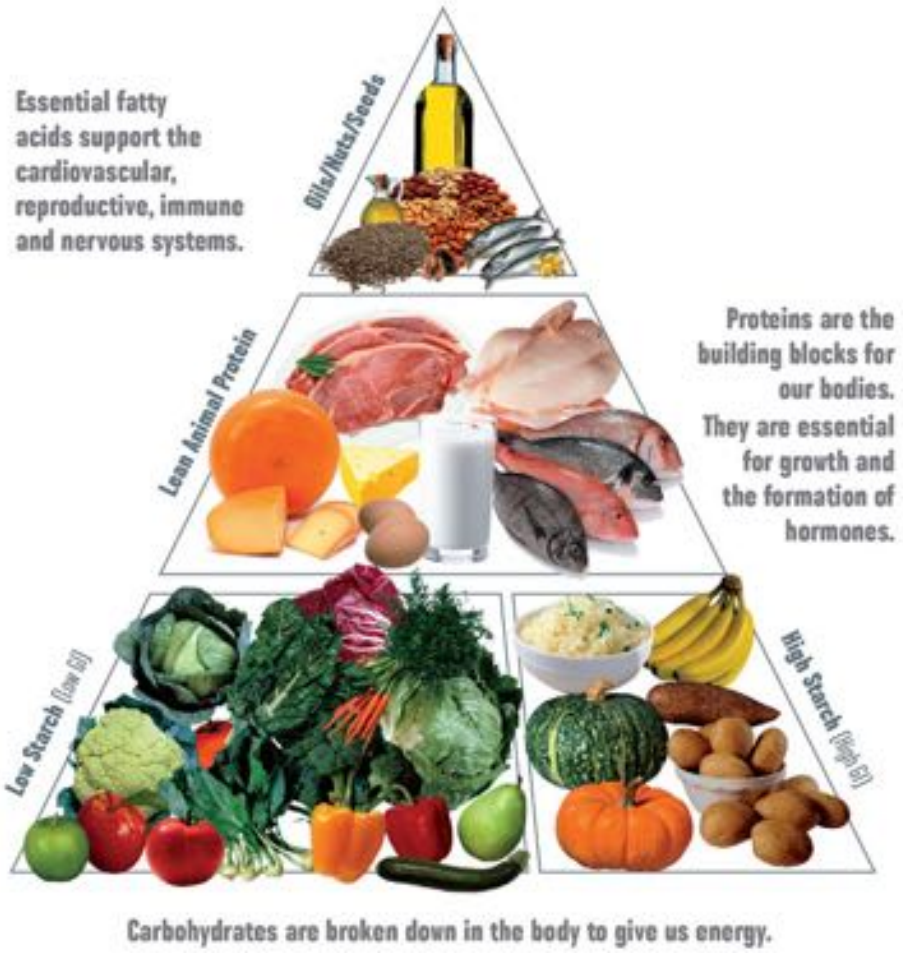


Figure 3–3 Schematic representation of oxidation–reduction potentials relative to the growth of certain microorganisms.

Jay et al. 2005. Modern Food Microbiology, 7th Ed. Springer. pg.50.

Intrinsic factors

- Nutrient content



- Antimicrobial constituents
  - Naturally occurring antimicrobial compounds

Plants: Eugenol (cloves), allicin (garlic), cinnamic aldehyde (cinnamon), thymol (sage, oregano)

Dairy: Lactoperoxidase, lactoferrin

Eggs: lysozyme, ovotransferrin

Intrinsic factors: Biological composition

- Biological structures
  - Protective covering that prevent microorganisms from gaining entry to growth promoting tissues underneath
    - Once compromised, protective effect is minimized
- Examples
  - Nut shells
  - Eggs
  - Fruit skins/peels
  - Animal hides

Intrinsic factors

Properties of a food product

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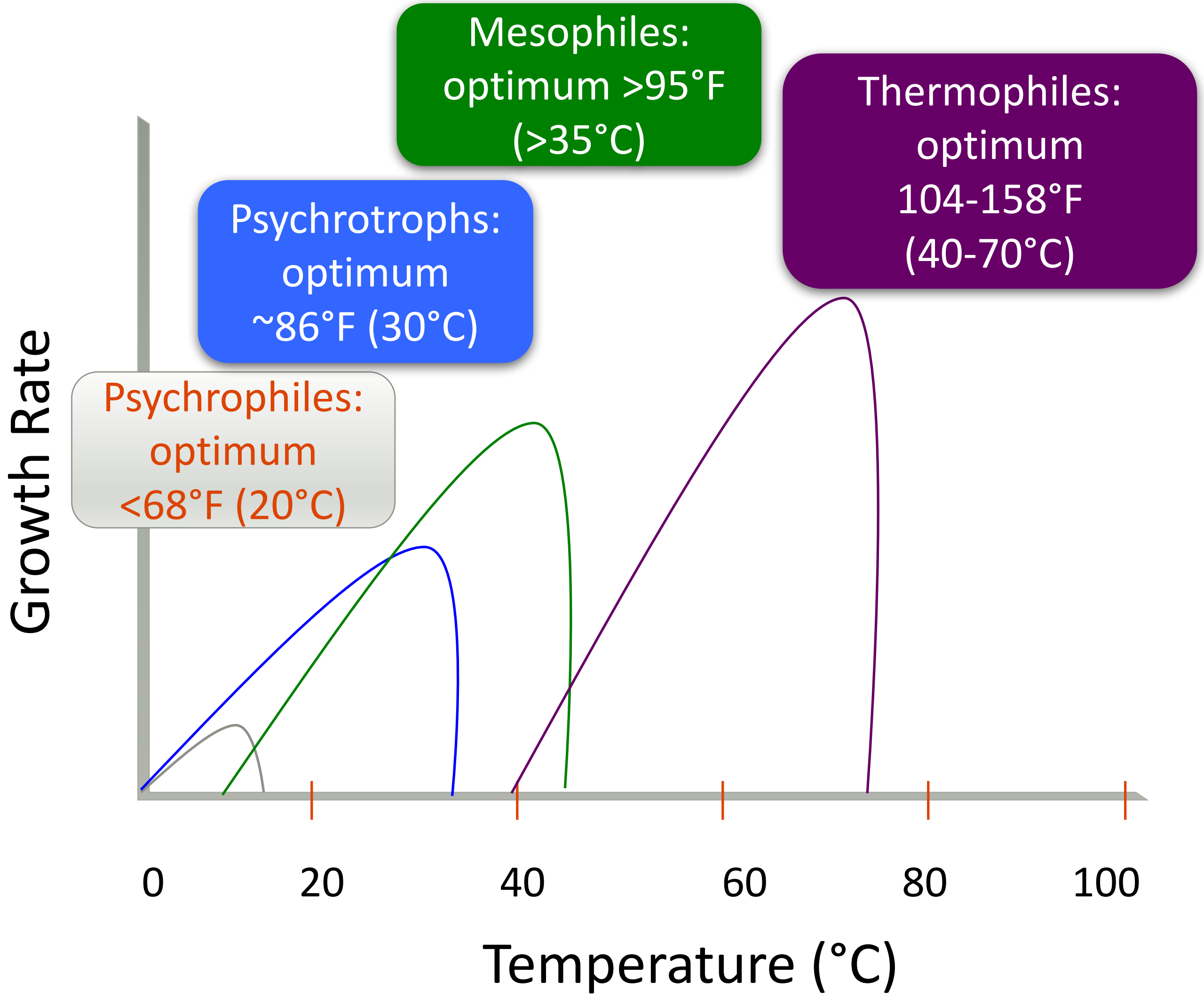
- Preadaptation to stress
- Stress response mechanisms

Temperature

- Storage temperatures selective or inhibitory for different microbes
  - Abusive temperatures may negatively influence product microbes
    - freeze out probiotics
  - Temperature can affect product quality
    - bananas



FDA, 2012. “Bad Bug Book”.
Graphic source: Kovacevic, J.

Relative humidity and gases

- The amount of water vapor present in air expressed as a % of the amount needed for saturation at the same temperature
- a_w of food is influenced by RH of storage environment

Low moisture foods

- a_w less than 0.6 must be kept dry, as they will pick up moisture from air in high RH
- Surface spoilage susceptible foods need low RH storage

High moisture foods

- Low RH storage can decrease food quality due to physical/chemical changes

To counteract low RH negative effects upon quality, gases can be added

- Modified atmosphere packaging (MAP)

High: >70% O_2, 20-30% CO_2, N_2

Low: <10% O_2, 20-30% CO_2, N_2

Photo source: G. Mondini
http://www.gmondini.com/gallery/map

Microbiota competition

- Microorganisms compete with each other for nutrients and space
  - Produce a variety of antimicrobial compounds (e.g. lactic acid bacteria)
    - Bacteriocins, hydrogen peroxide, organic acids (**lactic acid**)
    - Improve product quality/safety
  - Bacteriophage
    - Listeriaphage used to destroy *Listeria monocytogenes* in food production environments/in food

    e.g. Listex

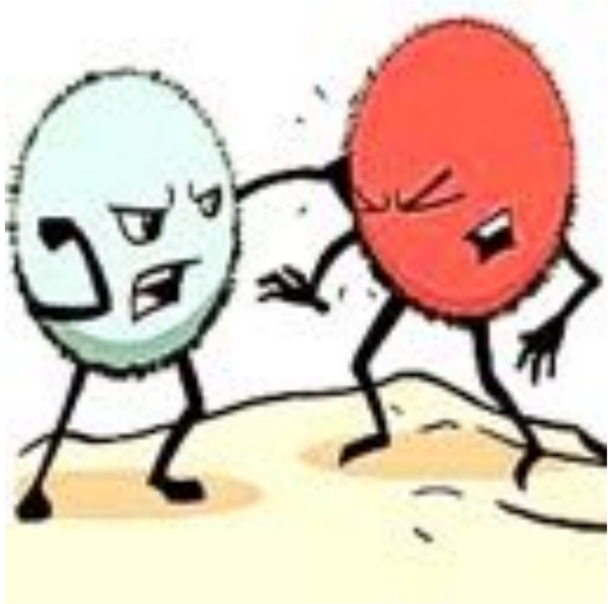


Image source: http://www.doctorbhatia.com/wp-content/uploads/2011/05/f-bacteria-fight.jpg

Intrinsic factors

Properties of a food product

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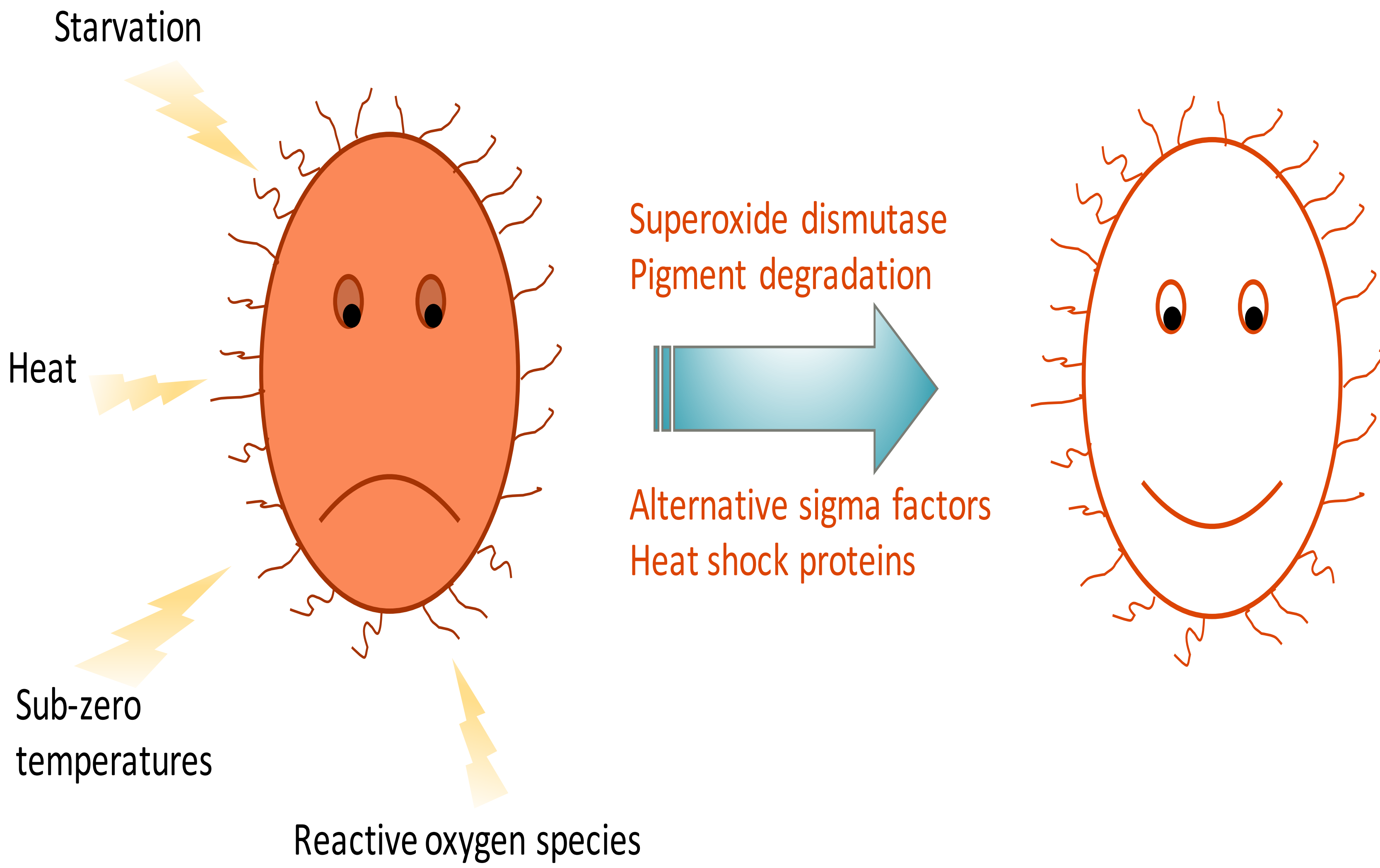
- Stress response mechanisms

Implicit factors

- Properties of microorganisms

Microorganism are commonly exposed to damaging elements in food processing environments.

They battle these conditions through sophisticated set of cellular stress responses.



Adapted from Adrienne Dolberry. 7.343 MIT OpenCourseWare, https://ocw.mit.edu.

Why is Listeria monocytogenes *(Lm) problematic in food processing?*

Listeria spp. background

- 17 species[1]
  - *L. monocytogenes* (*Lm*)
    - listeriosis in humans and animals
  - *L. ivanovii*
    - listeriosis in animals

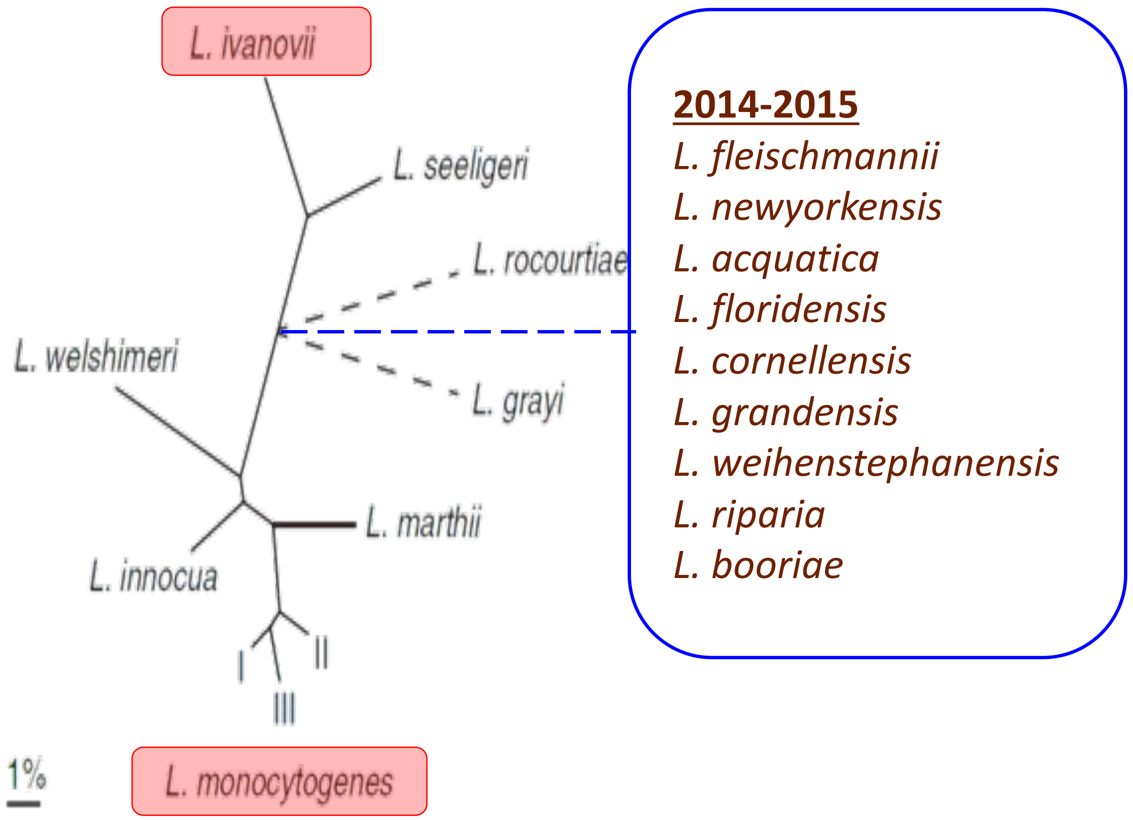


Fig 1. Phylogeny of *Listeria* spp. Adapted from Cossart (2011; PNAS 108:19484-91).

[1]Weller *et al.*, 2015. Int. J. Syst. Evol. Microbiol 65:286

Listeriosis disease

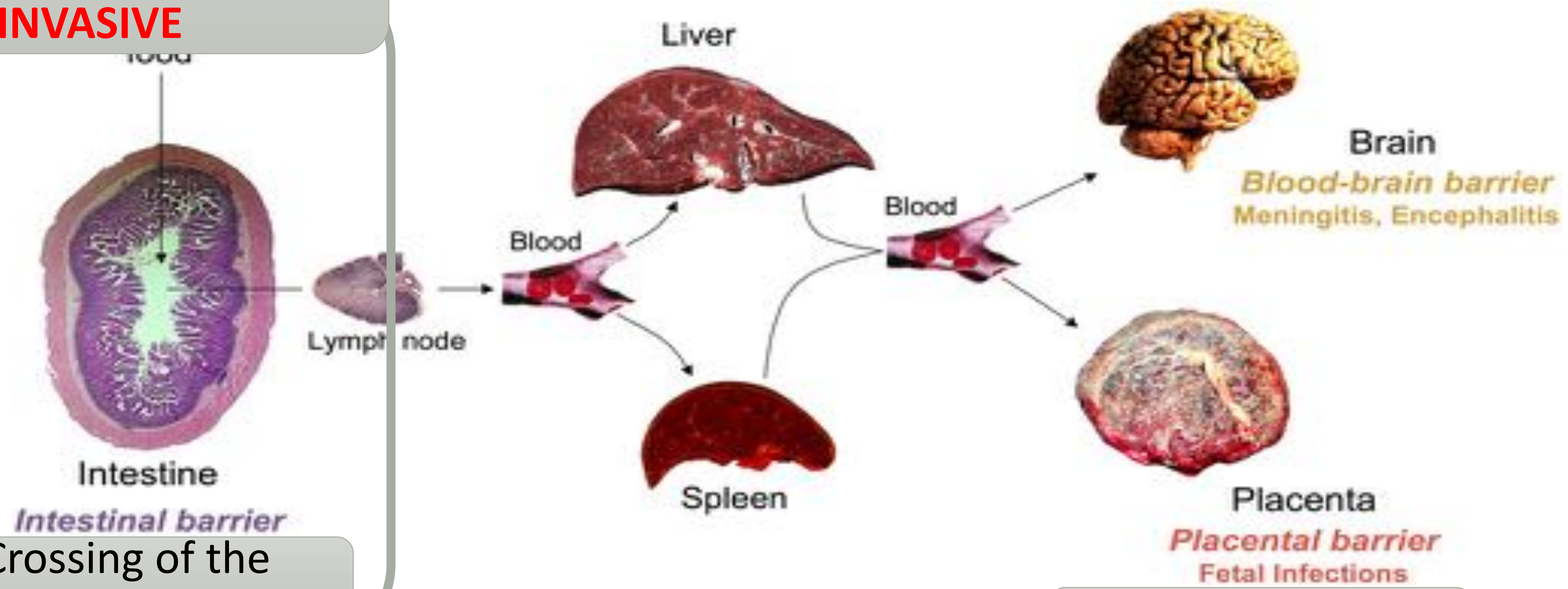
Healthy adults:

- mild gastroenteritis

NON-INVASIVE

Multiplication in the liver

Invasion of the brain



Crossing of the intestinal barrier

Colonization of uterus and fetus

Fig 2. *Listeria* infectious process and dissemination in human body. Adapted from Lecuit, 2007.

Listeriosis disease

Immunocompromised adults:

- mild gastroenteritis followed by septicemia, meningitis, endocarditis

INVASIVE

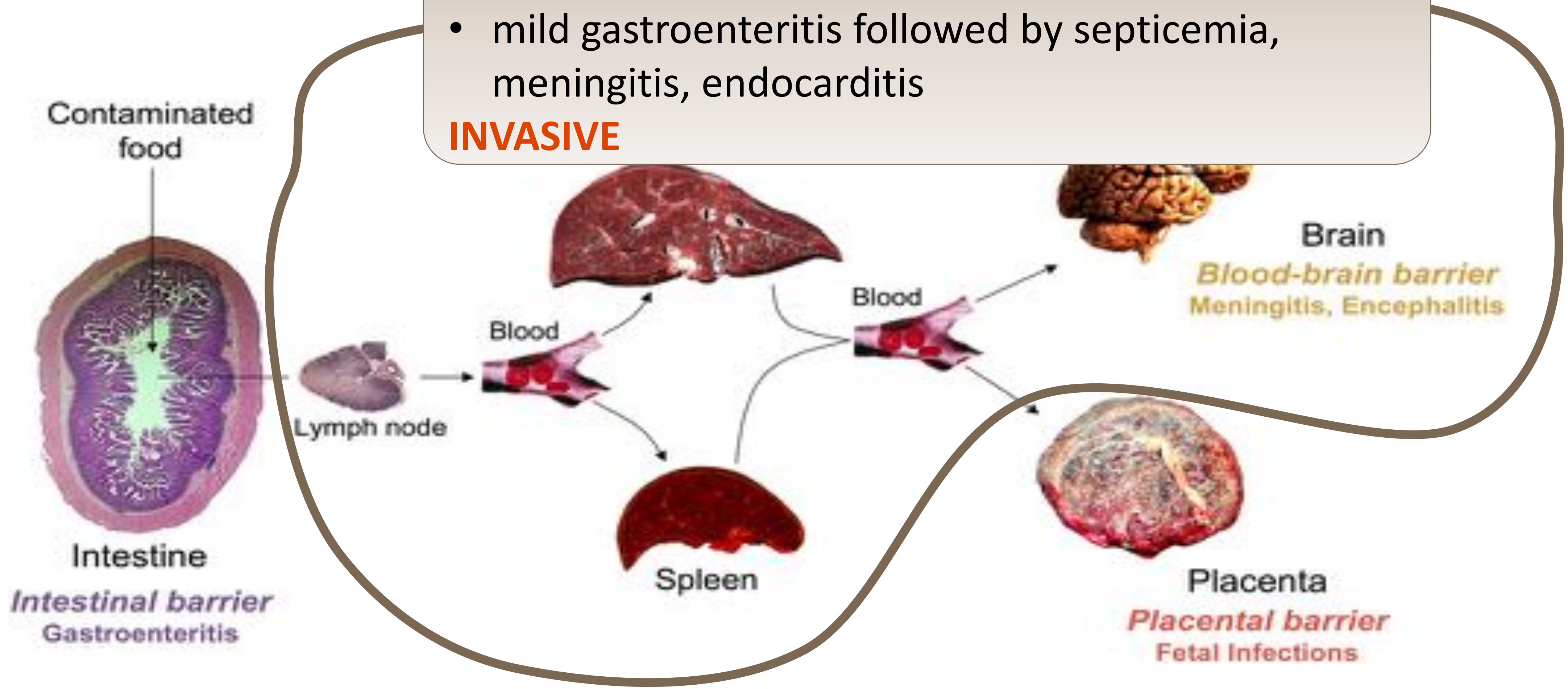
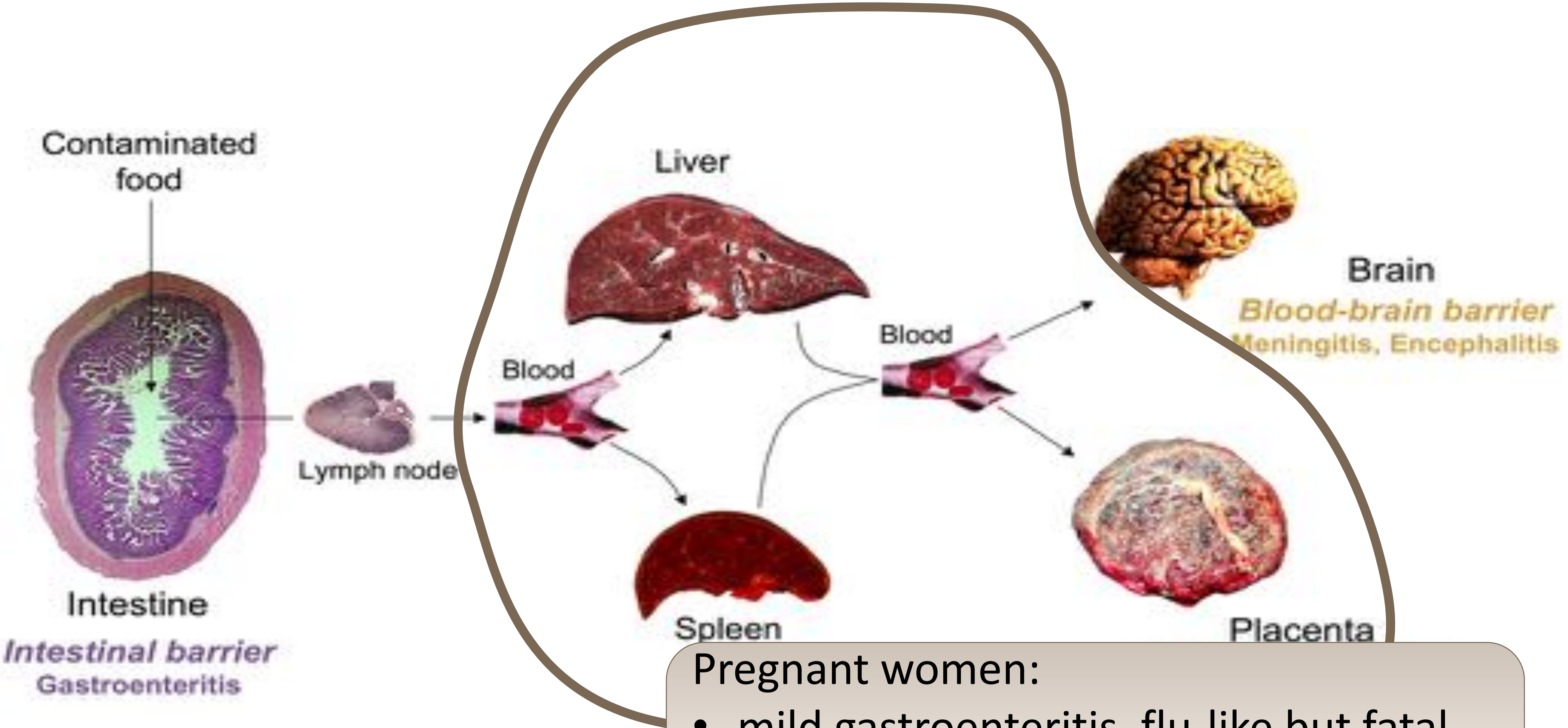


Fig 2. *Listeria* infectious process and dissemination in human body. Adapted from Lecuit, 2007.

Listeriosis disease

INVASIVE listeriosis
fatality rate **20 to 40%**



Pregnant women:

- mild gastroenteritis, flu-like but fatal or severe complications for fetus

INVASIVE

Fig 2. *Listeria* infectious process and dissemination in h
Adapted from Lecuit, 2007.

Why is *Lm* a problem in food industry?

- Food processing environment is a complex and dynamic environment
- Potential contamination reservoirs…

RAW MATERIALS

Recurring introduction of new microorganisms

PERSONNEL

Fecal (coliforms, enterococci, pathogens)

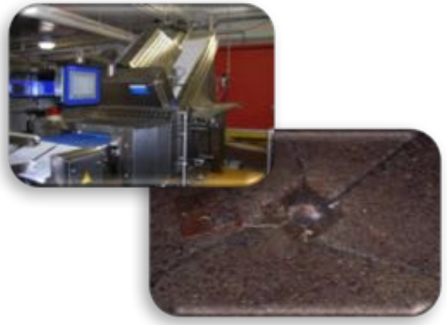
*Nasal, skin (*Staphylococcus aureus*), hair*

Ill and asymptomatic employees (Viruses -Norovirus, Hepatitis)

WATER

Contaminated water

Inappropriate washing & aerosol spread



PRODUCTION ENVIRONMENT

Food contact surfaces (FCS)

Floors, drains, utensils

Production equipment – fork lifts, hydraulic hand lifts, mats etc.

Photo source:
https://pixnio.com (raw materials, personnel 2, water 2); http://weclipart.com/ (personnel 1); https://pixabay.com (water 1), BCFPA (production environment 1)

Why is *Lm* a problem in food industry?

- Growth temperature: 31 to 113°F or -0.4 to 45°C
  - Highly cold tolerant!

Table 1. Generation times for *L. monocytogenes*.[1]

Temperature (°C/°F)	**0 to 1°C 32 to 34°F**	**4 to 5°C 39 to 41°F**	**9 to 10°C 48 to 50°F**
Time (h)	62 - 131	13 - 25	5 - 9

- Not heat resistant
  - Does not survive pasteurization
  - Heat tolerance may depend on strain, environment, previous heat shock

[1]Walker *et al.*, 1990. J Appl. Bacteriol. 68, 157-162.

Why is *Lm* a problem in food industry?

- Salt tolerance
  - One of the most halotolerant foodborne pathogens[2,3]
    - Grows at 10% (w/v) NaCl
    - Survives at 40% (w/v) NaCl
- pH requirement
  - Will grow at 4.4 to 9.4
  - Most food adjusted between 4-5

Fig. 3. Cheese soaked in brine.
Photo source: https://flic.kr/p/yAGQi4

- Water activity required for growth[2]
  - Around 0.92

[2]Health Canada, 2011; [3]Liu *et al.,* 2005. FEMS Microbiol. Lett. 15, 243.

Listeria monocytogenes (Lm)

- Infection causes severe illness in susceptible people – mortality 15-30%
- Primary sources: Occurs widely in agriculture (soil, plants and water)
- Transmitted by: Refrigerated RTE foods that support growth
- Contributing factors: Environmental pathogen spread by environmental contamination, equipment, people, incoming raw ingredients

Growth parameters	Minimum	Optimum	Maximum
Temperature	31°F (-0.4°C)	99°F (37°C)	113°F (45°C)
pH	4.4	7.0	9.4
a_W	0.92	-	-
Other	Non-sporeformer		
Atmosphere	Facultative - grows with or without oxygen		

Sources: ICMSF 1995 and Bad Bug Book 2nd edition

FSPCA FOOD SAFETY PREVENTIVE CONTROLS ALLIANCE

Why is Salmonella *problematic in food processing?*

Salmonella spp. background

- Two species
  - *S. enterica*
    - Six subspecies
    - Further divided into serotypes*: >2,500
      - <100 account for most human infections
  - *S. bongori*
    - 22 serotypes
    - Commonly associated with reptiles

*Single species of microorganisms which share distinctive surface structures.

Sources: Bad Bug Book 2nd edition and CDC *Salmonella* Atlas, 2013. https://www.cdc.gov/salmonella/pdf/salmonella-atlas-508c.pdf

Almond Board of California. PEM Book.
http://www.almonds.com/sites/default/files/pem_book.pdf

Salmonellosis

In US, each year:

>1.2 million illnesses   23,000 hospitalizations   450 deaths

Gastrointestinal illness

Nausea, vomiting, diarrhea, cramps, and fever. 6 to 72 h after exposure.

Last several days and taper off within a week. Mortality is <1%.

Symptoms go away but long-term arthritis may develop.

Typhoidal illness

High fever, diarrhea or constipation, aches, headache, and lethargy (drowsiness or sluggishness), and, sometimes, a rash. 1 to 3 weeks, up to 2 months after exposure.

Without treatment, mortality up to 10%.

Often associated with sewage-contaminated drinking water, pets,

Why is *Salmonella* a problem?

- Survives for a long period of time under dry conditions
  - *Salmonella* Enteriditis Phage Type 30 can survive for up to 550 days on almond kernels held under a variety of common storage conditions Uesugi et al., 2006. JFP 69:1851-1857.
  - Can survive for up to 24 weeks in peanut butter, with a higher incidence of survivors in product stored at 41°F (5°C) versus 69.8°F (21°C) Burnett et al., 2000. J Appl. Bacteriol. 89:472-477.
  - Low a_w detrimental to *Salmonella* survival at 131°F (55°C) or 140°F (60°C), but… Mattick et al., 2001. AEM 67:4128-4136.
    - If temperatures greater than 158°F (>70°C) = protection!
      - Harder to inactivate at higher temperature

Almond Board of California. PEM Book.
http://www.almonds.com/sites/default/files/pem_book.pdf

Why is *Salmonella* a problem?

- Can persist for prolonged time in environment
  - *Salmonella* Enteriditis Phage Type 30 has persisted in a single almond orchard for over a 5 years …
    - Persistence and growth in almond orchard soils for extended periods of time
  - Survives for weeks in aquatic environments, including irrigation water
  - Survives drying of the almond hulls
  - Colonizes conveyor belts, processing floors, dust samples, employee shoes, brooms… etc.

Almond Board of California. PEM Book.
http://www.almonds.com/sites/default/files/pem_book.pdf

Salmonella spp.

- Infection causes nausea, vomiting, diarrhea, fever, headache
- Primary sources: Intestinal tract of people and animals
- Transmitted by meat, poultry, eggs, raw milk, unpasteurized juice, many other foods (nuts, spices, produce, chocolate, flour)
- Contributing factors: cross-contamination, undercooked food, poor agricultural practices

Growth parameters	Minimum	Optimum	Maximum
Temperature	41°F (5.2°C)	95-109°F (35-43°C)	115°F (46.2°C)
pH	3.7	7-7.5	9.5
a_W	0.94	0.99	>0.99
Other	Non-sporeformer		
Atmosphere	Facultative - grows with or without oxygen		

Sources: ICMSF 1995 and Bad Bug Book 2nd edition

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Food processing environment

What are the microbial hazards?

Why and how do they survive?

Where do they come from?

How do we prevent or control them?

Microbial sources

- Diverse habitats (but overlapping!)
  - *E. coli*
    - Soil and water, plants, GI tract, people
  - *Listeria*
    - Soil and water, plants, people, animal feeds, animal hides
  - *Salmonella*
    - GI tract, animal feeds

Table 2–2 Relative Importance of Eight Sources of Bacteria and Protozoa to Foods

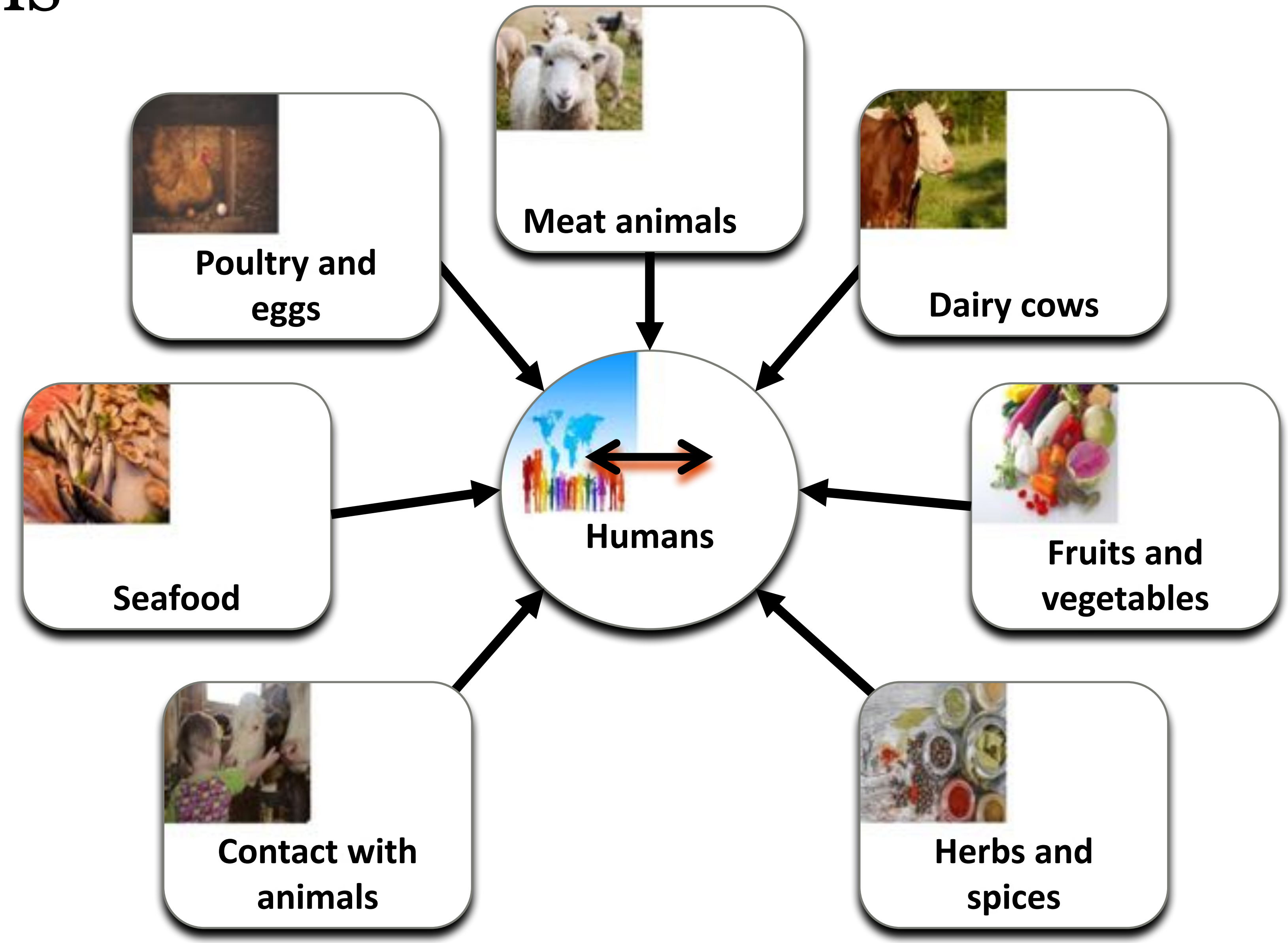
Organisms	*Soil and Water*	*Plants/Products*	*Food Utensils*	*Gastrointestinal Tract*	*Food Handlers*	*Animal Feeds*	*Animal Hides*	*Air and Dust*
Bacteria								
Acinetobacter	XX	X	X				X	X
Aeromonas	XX[a]	X						
Alcaligenes	X	X	X	X			X	
Alteromonas	XX[a]							
Arcobacter	X							
Bacillus	XX[b]	X	X		X	X	X	XX
Brochothrix		XX	X					
Brevibacillus	X	X						X
Burkholderia		XX						
Campylobacter				XX	X			
Carnobacterium	X	X	X					
Citrobacter	X	XX	X	XX				
Clostridium	XX[b]	X	X	X	X	X	X	XX
Corynebacterium	XX[b]	X	X		X		X	X
Enterobacter	X	XX	X	X			X	
Enterococcus	X	X	X	XX	X	X	X	X
Erwinia	X	XX	X					
Escherichia	X	X		XX	X			
Flavobacterium	X	XX					X	
Hafnia	X	X		XX				
Kocuria	X	X	X		X		X	X
Lactococcus		XX	X	X			X	
Lactobacillus		XX	X	X			X	
Leuconostoc		XX	X	X			X	
Listeria	X	XX			X	X	X	
Micrococcus	X	X	X		X	X	X	XX
Mycobacterium[c]		X						
Moraxella	X	X					X	
Mycobacterium								
Paenibacillus	XX	X	X					XX
Pandoraea		X						
Pectobacterium	X	XX						
Pantoea	X	X		X				
Pediococcus		XX	X	X			X	
Proteus	X	X	X	X	X		X	
Pseudomonas	XX	X	X			X	X	
Psychrobacter	XX	X	X				X	
Salmonella				XX		XX		
Serratia	X	X	X	X		X	X	
Shewanella	X	X						
Sphingomonas	X	X						
Shigella				XX				
Stenotrophomonas	X	XX						
Staphylococcus				X	XX		X	
Vagococcus	XX			XX				
Vibrio	XX			X				
Weissella		XX	X					
Yersinia	X	X		X				
Protozoa								
C. cayetanensis	X	X		X				
C. parvum	XX			X	X			
E. histolytica	XX			X	X			
G. lamblia	XX			X	X			
T. gondii		X		XX				

Note: XX indicates a very important source.

[a]Primarily water.
[b]Primarily soil.
[c]Nontuberculous.

Jay et al., 2005. Modern Food Microbiology, 7th Ed. Springer. Pg.18-19.

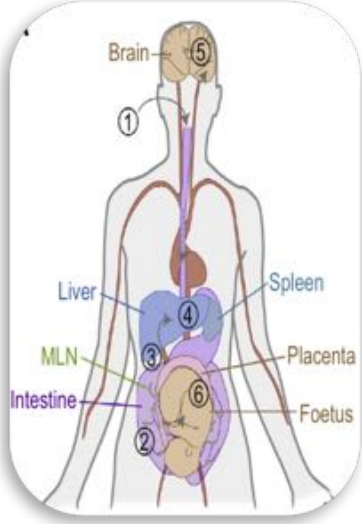
Sources of foodborne pathogens



Ray, 2013. pp. 34

Contamination routes

Natural environment/raw ingredients → Food processing environment → Preparation of ready-to-eat food → Human host



Graphic source: Kovacevic, J.

Hindawi Publishing Corporation
BioMed Research International
Volume 2015, Article ID 131623, 12 pages
http://dx.doi.org/10.1155/2015/131623

Research Article

Listeriosis Outbreaks in British Columbia, Canada, Caused by Soft Ripened Cheese Contaminated from Environmental Sources

Lorraine McIntyre,[1] Lynn Wilcott,[1] and Monika Naus[2,3]

Soft ripened cheese (SRC) caused over 130 foodborne illnesses in British Columbia (BC), Canada, during **two separate listeriosis outbreaks.** Multiple agencies investigated the events that lead to cheese contamination with *Listeria monocytogenes* (L.m.), an environmentally ubiquitous foodborne pathogen. In both outbreaks pasteurized milk and the pasteurization process were ruled out as sources of contamination. In outbreak A, environmental transmission of L.m. likely occurred from farm animals to personnel to culture solutions used during cheese production. In outbreak B, birds were identified as likely contaminating the dairy plant's water supply and cheese during the curd-washing step. **Issues noted during outbreak A included the risks of operating a dairy plant in a farm environment, potential for transfer of L.m. from the farm environment to the plant via shared toilet facilities, failure to clean and sanitize culture spray bottles, and cross-contamination during cheese aging.** **L.m. contamination in outbreak B was traced to wild swallows defecating in the plant's open cistern water reservoir and a multibarrier failure in the water disinfection system.** These outbreaks led to enhanced inspection and surveillance of cheese plants, test and release programs for all SRC manufactured in BC, improvements in plant design and prevention programs, and reduced listeriosis incidence.

Point source contamination - 2002 listeriosis outbreak in BC, Canada

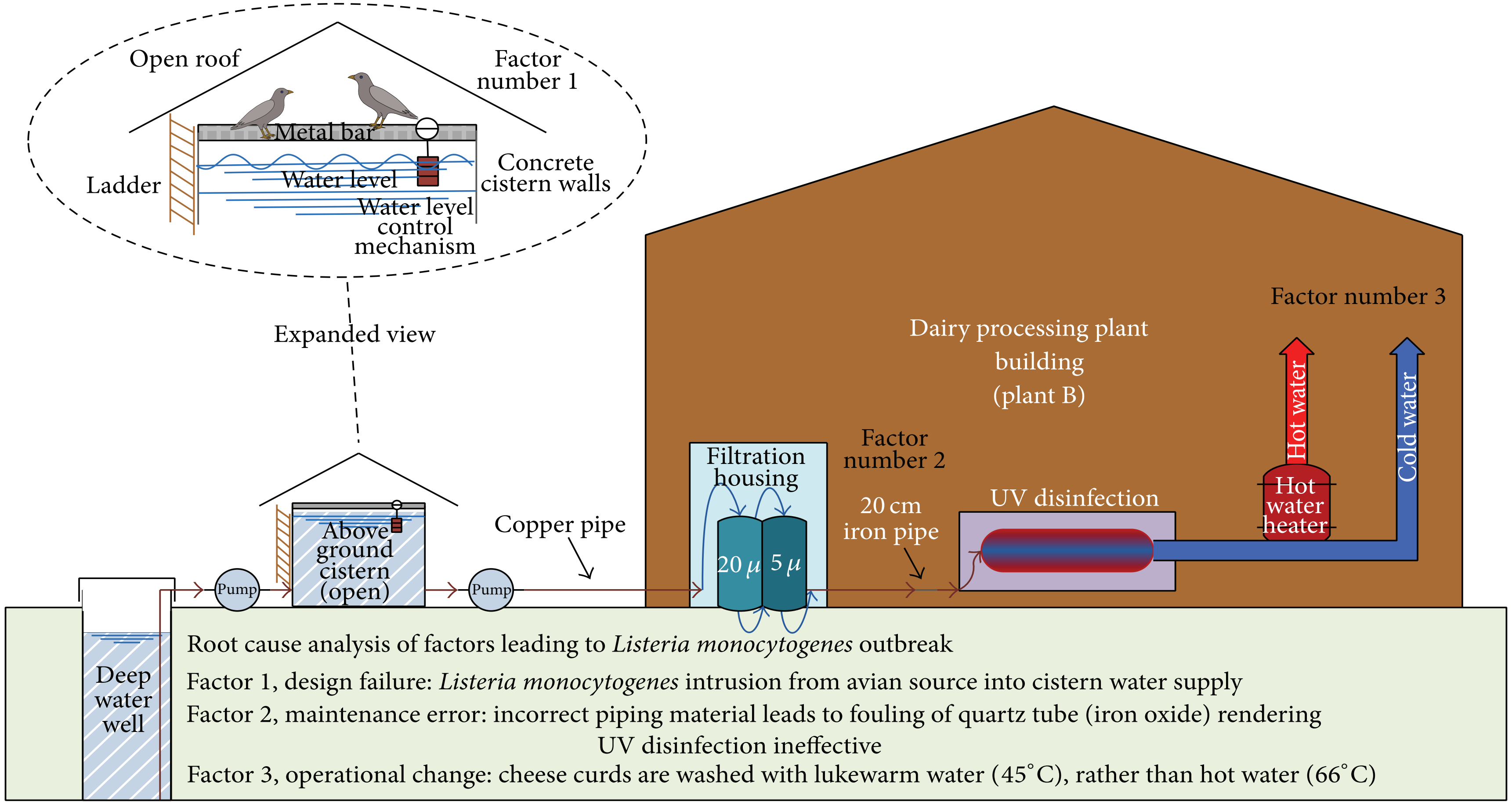


FIGURE 2: Schematic diagram of water supply system in dairy processing plant B.

McIntyre *et al.*, 2015. BioMed Res. Internat. http://dx.doi.org/10.1155/2015/131623

Journal of Food Protection, Vol. 75, No. 2, 2012, Pages 216–224
doi:10.4315/0362-028X.JFP-11-300

Occurrence and Distribution of *Listeria* Species in Facilities Producing Ready-to-Eat Foods in British Columbia, Canada

JOVANA KOVAČEVIĆ,[1]* LORRAINE F. McINTYRE,[2] SARAH B. HENDERSON,[2] AND TOM KOSATSKY[2]

FIGURE 3. The joint presence of *Listeria* spp. and *L. monocytogenes* in the processing environment and *L. monocytogenes* in food.

TABLE 1. *Types of surfaces sampled for recovery of* Listeria *spp. in ready-to-eat dairy, fish, and meat processing facilities*

Type of surface:		
Non–food contact	Close-to-food contact	Food contact
Drain +	Walls adjacent to food handling surfaces +	Work table +
Sides/legs:	Sides/legs:	Packaging counter
Cart +	Slicer +	Food racks/shelves +
Conveyor +	Packaging table +	Slicer
Vat	Shrink wrapper	Cutting board +
Table +	Work table +	Food bin
Refrigerator	Vacuum packer	Food display basket/bin/insert
Doors	Counter space	Food mold
Area under wash sink +	Silent cutter	Filler bowl
Support beams	Scale	Inside of vat pipes
Trolley wheels	Cup/jug filler	Cutting utensils
Bottom shelves of packaging/wrapping tables	Showcase/display cooler door handle and interior	

Kovacevic et al., 2012. JFP 75:216-224.

Transient vs. persistent contamination

Table 2. Examples demonstrating that certain strains of *L. monocytogenes* can become established and persist in the food-processing environment.

Type of food produced at plant	Time of persistence[a]	Country	Implicated in illness?	Serotype(s)[b]	Reference(s)
Cheese	4 years	Switzerland	Yes	4b	*5*
Cheese, blue veined	7 years	Sweden	No	3b	*94*
Cheese, goat	11 months	United Kingdom	Yes	4b	*3, 63*
Fish, smoked	Months	Switzerland	No	Several	*6*
	14 months	Finland	No	1/2a (86%), 4b (14%)	*53*
	Months	United States	No	ND	*70*
Frankfurters	4 months	United States	Yes	1/2a	*16, 95*
Frankfurters (outbreak strain was not isolated from the plant)	Months	United States	Yes	4b	*17*
Ice cream	7 years	Finland	No	1/2	*66*
Meat, sliced lunch	4 years	Norway	No	ND	*69*
Mussels, smoked	3 years	New Zealand	Yes	1/2	*7*
Pâté (product from one plant was the source of an outbreak from 1987 to mid-1989)	2 years	United Kingdom	Yes	4b(x), 4b	*64, 72*
Pork tongue in aspic (outbreak strain recovered from the implicated plant)	Months	France	Yes	4b	*50, 86*
Poultry, cooked	1 year	Ireland	No	1/2	*57*
Poultry, cooked deli products (outbreak strain matched a strain previously isolated from the same plant *(95)*)	12 years	United States	Yes	4b	*89*
Salmon, cold smoked	4 years	Denmark	No	ND	*31*
Salmon, smoked	8 months	Norway	No	ND	*82*
Seafood, smoked salmon	Months–2 years	Norway	Possibly	4, 1	*81*
Shrimp, raw shelled frozen	NS	Brazil	No	1, 4b	*25*
Trout/salmon, gravad	1 month	Sweden	No	4b	*60*
Trout, gravad and cold smoked	11 months	Sweden	Yes (gravad)	4b	*28*
Trout, smoked/salmon, gravad	>4 years	Sweden	Possibly	1/2a	*59*
Trout, cold smoked	NS	Finland	No	1/2	*2*

[a] NS, not stated.
[b] ND, not determined.

Tompkin, 2002. J Food Prot. 65:709-725.

Review of salmonellosis outbreaks

- Tomato-related
  - Pointed to packinghouses or produce fields *but*
    - Direct isolation of *Salmonella* from the production environment is rare!
  - Contaminated water also a source
- Sprout-related
  - Contaminated seeds
- Processed foods-related
  - Cross-contamination from surfaces
  - Biofilm formers, resistance to desiccation, heat

Landon et al., 2012. Pathogens. 1:128-155.

Table 1. Selected Outbreaks of Human Gastroenteritis Caused by *S. enterica*.

Food Vehicle	*S. enterica* Serovar	Cases	Year	Traceback	Reference
Tomato	Javiana	176	1990	Packing plant	[67]
Tomato	Montevideo	100	1993	Packing plant	[67]
Tomato	Baildon	86	1998	Grower/Packing plant	[68]
Tomato	Newport	510	2002	Pond water at grower	[69]
Tomato	Braenderup	125	2004	Packing plant	[70,71]
Tomato	Multiserotype	561	2004	Packing plant	[70,72]
Tomato	Braenderup	82	2005	Grower	[73]
Tomato	Newport	72	2005	Pond water at grower	[69,73]
Tomato	Typhimurium	190	2006	Packing plant	[73,74]
Tomato	Newport	115	2006	Not stated	[73]
Alfalfa sprouts	Stanley	>242	1995	Alfalfa Seeds	[75]
Alfalfa sprouts	Newport	>133	1995	Alfalfa Seeds	[76]
Alfalfa sprouts	Montevideo	417	1996	Alfalfa Seeds	[77]
Alfalfa sprouts	Melegridis	75	1996	Alfalfa Seeds	[77]
Alfalfa/Clover	Senftenberg	60	1997	Clover Seeds	[77]
Alfalfa sprouts	Infantis/Anatum	109	1997	Alfalfa Seeds	[78]
Alfalfa sprouts	Havana	18	1998	Alfalfa Seeds	[77]
Alfalfa sprouts	Cubana	22	1998	Alfalfa Seeds	[77]
Alfalfa sprouts	Mbandaka	87	1999	Alfalfa Seeds	[79]
Alfalfa sprouts	Muenchen	157	1999	Alfalfa Seeds	[80]
Clover sprouts	Typhimurium	112	1999	Clover seeds	[81]
Alfalfa sprouts	Kottbus	31	2003	Alfalfa seeds	[82]
Alfalfa sprouts	Saintpaul	228	2009	Alfalfa Seeds	[83]
Alfalfa sprouts	Newport	44	2010	Not Stated	[84]
Alfalfa/Clover	Typhimuirum (I 4,[5],12:i:)	140	2010	Not stated	[85]
Alfalfa sprouts	Enteriditis	25	2011	Not stated	[86]
Paprika Chips	Saintpaul, Javiana, and Rubislaw	>670	1993	Paprika powder	[87]
Toasted Oat Cereal	Agona	209	1998	Air-handling system and vitamin spray mixer	[88]
Squid/shrimp Crackers	Chester and Oranienberg	1634	1999	Unknown	[89,90]
Chocolate	Durham	110	1970	Cocoa powder	[91]
Chocolate	Eastbourne	217	1973	Cocoa bean	[92,93]
Chocolate	Napoli	245	1982	Not stated	[94]
Chocolate	Nima	24	1985	Not stated	[95]
Chocolate	Typhimurium	349	1987	Avian wildlife reservoir suspected	[96]
Chocolate	Oranienburg	439	2001	Unknown	[97]

Sources of contamination

Raw ingredients

Marshmallow product with raw eggs

- 36 cases of salmonellosis in 1995 (Lewis et al., 1996)

Paprika-powdered potato chips and paprika powder

- 1,000 cases of salmonellosis in Germany in 1993 (Lehmacher et al., 1995)

Personnel

Cross-contamination in a Japanese oil meal factory – 2006 study by Morita et al., 2006

- Operator footwear became contaminated with *Salmonella* 1 day after being disinfected
- 90% positive contamination rate on workers gloves

Finn et al., 2013. Front Microbiol. 4:331.

Sources of contamination

Equipment, water, air

1985 *S.* Ealing outbreak in UK, infant dried milk

- Cracks in the walls of the spray dryer (Rowe et al., 1987)

Outbreak of *S.* Agona from a toasted oat cereal

- Processing machinery was open to the atmosphere (Breuer, 1999)

Peanut butter and peanut paste in the US in 2008–2009

- >700 cases of illness and failure to prevent contamination to equipment, containers, and utensils

Pest control

Pests can act as a transmission vector for *Salmonella*

- 41 rodents captured in oil meal facility and tested in Japan, with 46% positive for *Salmonella* (Morita et al., 2006)

Wild birds can carry a variety of different *Salmonella* serotypes (Pennycott et al., 2006)

Finn et al., 2013. Front Microbiol. 4:331.

Food processing environment

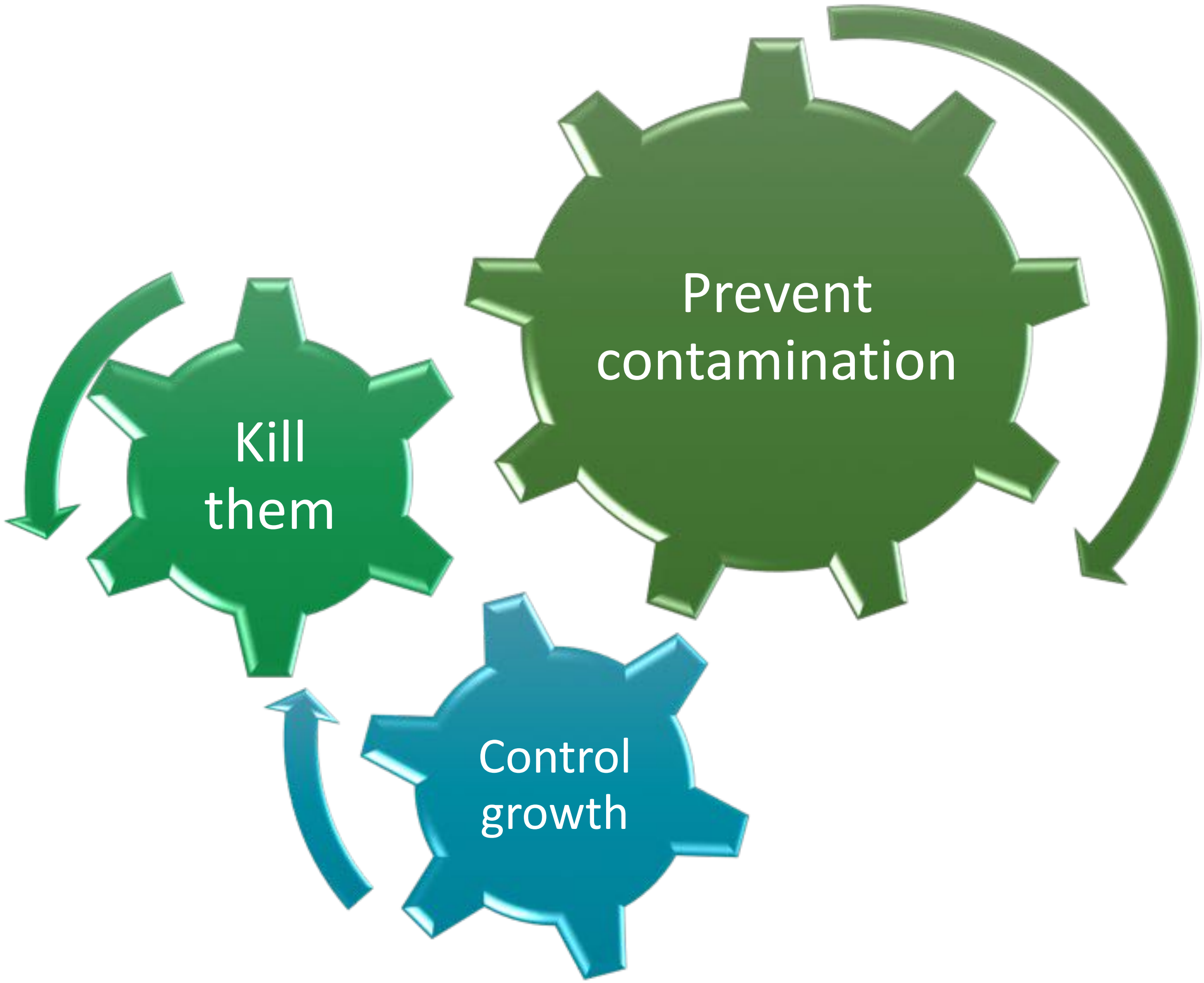
What are the microbial hazards?

Where do they come from?

Why and how do they survive?

How do we prevent or control them?

Potential control methods for bacteria



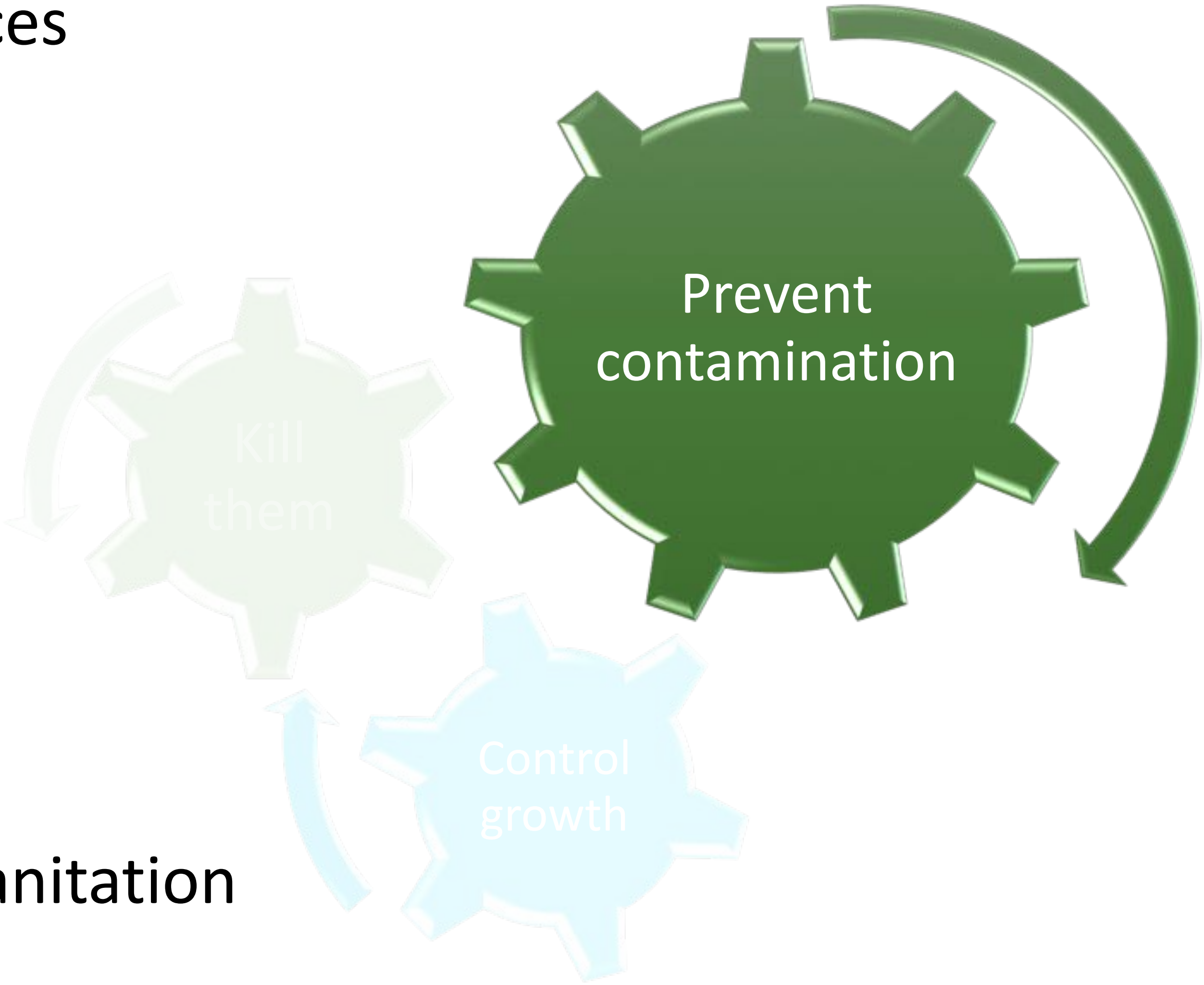
Potential control methods for bacteria

Proper hygiene practices

Preventing cross contamination from raw to ready-to-eat

Preventing contamination from equipment, personnel

Proper cleaning and sanitation



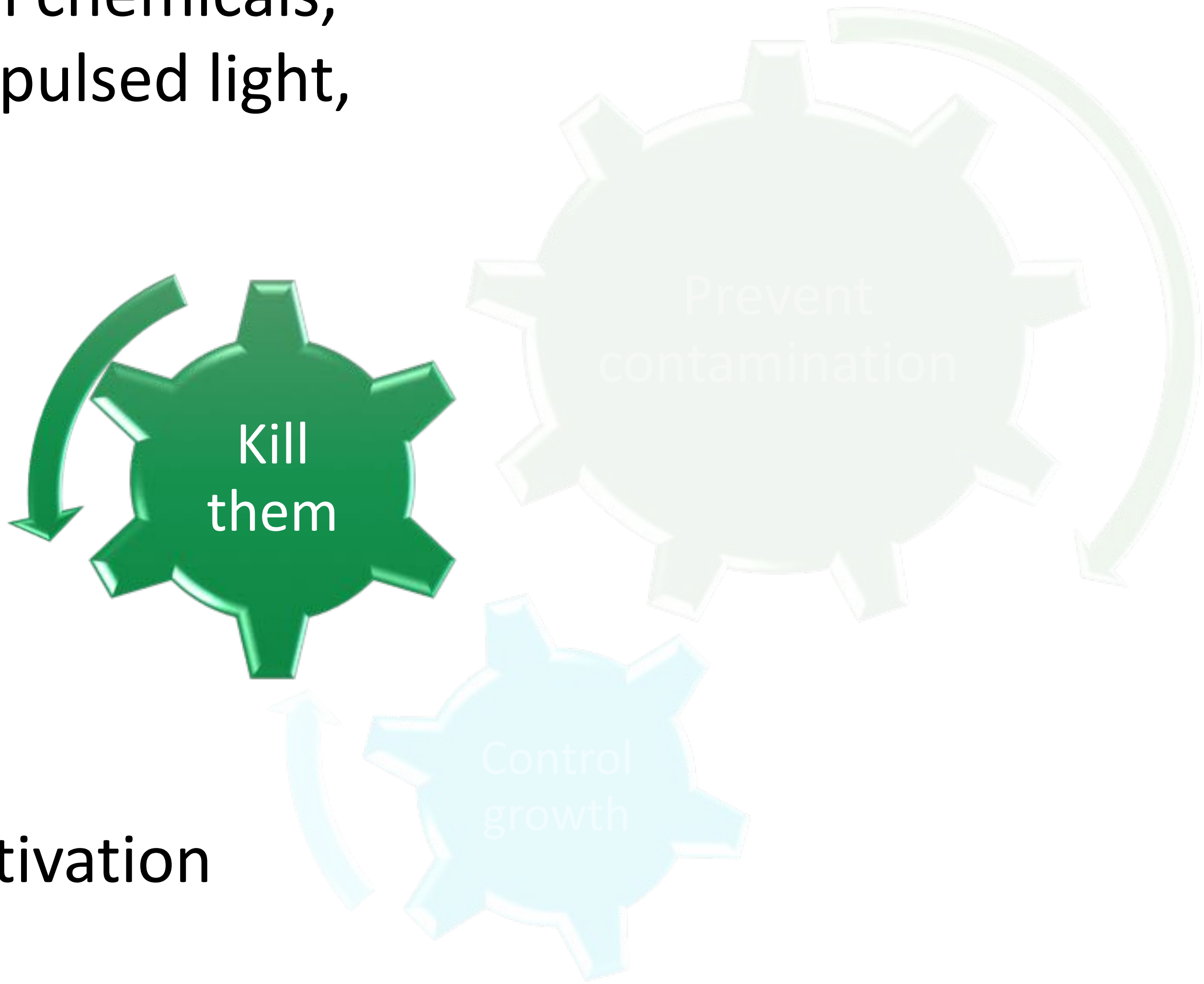
Potential control methods for bacteria

Heat, acid, antimicrobial chemicals, irradiation, ultrasound, pulsed light, high pressure…

Conditions influence rate of kill

- Time, temperature, food composition…

Models can predict inactivation



Potential control methods for bacteria

Understand intrinsic and extrinsic factors!

- Food – a nutrient source
- Temperature and time
- pH – acidity or alkalinity measure
- Water
- Proper atmosphere
- Microbial competition
- Preservatives

Reducing growth reduces risk but may not eliminate it!

Apply hurdle concept

Multiple factors are combined to control food microorganisms

- Temp, a_w, pH, Eh, antimicrobials

Can lead to milder processing, increasing fresher food product availability

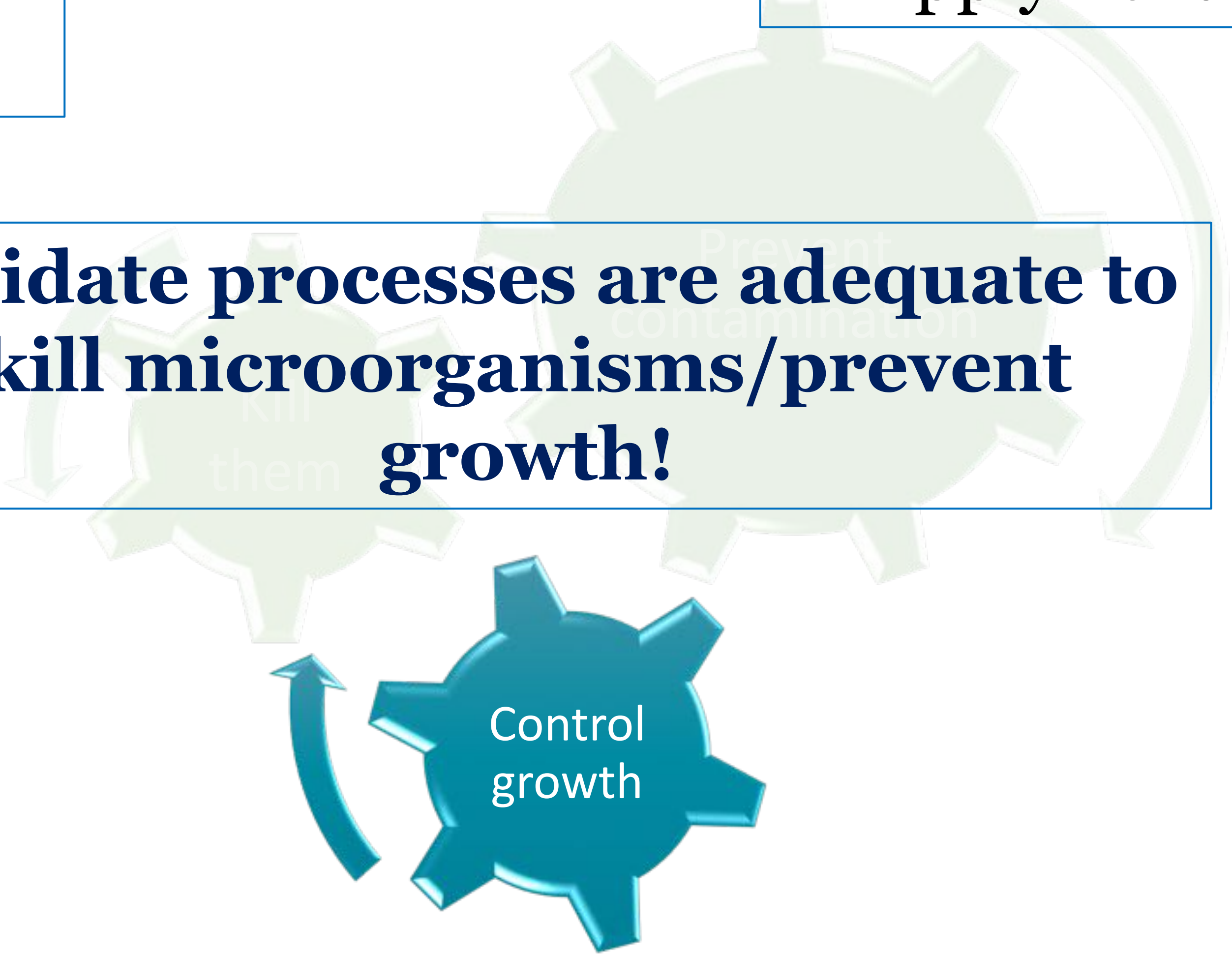
- Gas packaging, bioconservation, bacteroicins, ultrahigh pressure treatment, edible coatings

Potential control methods for bacteria

Understand intrinsic and extrinsic factors!

Apply hurdle concept

Validate processes are adequate to kill microorganisms/prevent growth!



Summary

- Foods and food processing environments may become contaminated with pathogens found in nature, animals, humans and various sources
- Two common pathogens of concern in food processing environments are *Listeria monocytogenes* (wet environment) and *Salmonella* spp. (dry environment)
- Environmental pathogens may be able to survive and persist in processing environment for a long time
- Microbial growth and survival is affected by intrinsic, extrinsic and implicit factors
- Potential controls for microbiological hazards include: preventing contamination, killing microorganisms through processing, controlling growth of microorganisms through manipulation of growth conditions (intrinsic/extrinsic factors)